AFOSR-TR- 79-1331

LEVEL II

SEMIANNUAL TECHNICAL REPORT

No. 3

1 January 1979 to 30 June 1979

Regional Seismic Wave Propagation

RONDOUT ASSOCIATES, INCORPORATED
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Sponsored by
Advanced Research Projects Agency (DOD)
ARPA Order No. 3291-13
Monitored by AFOSR Under Contract # F49620-78-C-0043

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) Unclassified

19 REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER 18 AFOSR TR-79-1331	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 Regional Seismic Wave Propagation.		5. TYPE OF REPORT & PERIOD COVERED Semiannual Technical Report 1 January 1979-30 June 1979
		6. PERFORMING ORG. REPORT NUMBER 14 03-79-1
7. AUTHOR(s) 10 Paul W. Pomeroy		8. CONTRACT OR GRANT NUMBER(s) 15 F49620-78-C-0043, ARPA Order-3291
9. PERFORMING ORGANIZATION NAME AND ADDRESS Rondout Associates, Incorporated P.O. Box 224 Stone Ridge, New York 12484		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element: 62701E Program Code: 8F10 ARPA Order: 3291-13
11. CONTROLLING OFFICE NAME AND ADDRESS DARPA/NMR 1400 Wilson Blvd. Arlington, VA 22209		12. REPORT DATE 11 31 July 1979
		13. NUMBER OF PAGES 47
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) AFOSR/NP Bolling AFB Wash DC 20332 12 43		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

9 Semiannual technical rept. no. 3, 1 Jan - 30 Jun 79,

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Seismic Discrimination
Seismic Wave Propagation
Rayleigh Waves
Group Velocity - Lg
Energy Ratio - Lg
USSR Earthquakes
Attenuation - Lg

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The research reported here was carried out to enhance our understanding of seismic wave propagation at regional distances in the central portion of the USSR. Results in this region are contrasted with those from the Western USSR and with data from eastern North America.

The principal conclusions of this study are:

1. For the 25 E. Kazakh and 4 other USSR presumed explosions studied, Lg(Z) amplitudes are of the same order as P9Z) wave amplitudes. This result is in agreement with earlier results from the western USSR, but it is in sharp contrast

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3. Group velocities for the eastern Kazakh events cluster around 3.5 km/sec. (3.27 to 3.70 at KBL and 3.14 to 3.70 at MHI), Data for three other USSR presumed explosions fall in the 3.10 to 3.25 km/sec. range. Group velocities for 5 Gazli earthquakes fall in the range 3.0 to 3.15 km/sec.

4. Energy ratios in Lg(Z) vary from .48 to 1.33 for the E. Kazakh events in agreement with earlier results from the western USSR.

5. Lg(Z) amplitude vs distance data can be approximated by a straight line indicating a variation of $1/\Delta^3$ in agreement with USSR authors who suggest a slope lying between $1/\Delta^2$ and $1/\Delta^3$.

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TABLE OF CONTENTS

TABLE OF ILLUSTRATIONS

TABLE OF ILLUSTRATIONS (Cont'd.)

TECHNICAL REPORT SUMMARY

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The principal conclusions of this study are:

1. For the 25 E. Kazakh and 4 other USSR presumed explosions studied, Lg(Z) amplitudes are of the same order as P(Z) wave amplitudes. This result is in agreement with earlier results from the western USSR, but it is in sharp contrast to observations by Russian authors who have reported Lg/P wave ratios of up to 100.

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INTRODUCTION

This report deals with the significant results of an ongoing study initiated in December, 1977, to analyze seismic wave propagation in eastern North America, and geologically and tectonically similar areas in other parts of the world. Particular research efforts in the overall study include:

1. The investigation of the regional propagation of high frequency L_g with special emphasis on frequency content, propagation velocity and attenuation characteristics as well as the presence or absence of L_g on particular seismograms.

2. The investigation of the regional propagation of continental first and higher mode Love and Rayleigh waves, particularly the shape of group velocity curves and attenuation characteristics.

The goal of this research is to discover and evaluate the use of discriminants involving seismic waves observed at regional distances, to determine the geographic variations in the parameters used in those discriminants and to understand the propagation of regional seismic waves. Although the discrimination of underground nuclear explosions from earthquakes at teleseismic distances is generally understood above a certain magnitude threshold, the problem of discrimination between the two types of sources at regional distances (5°- 20°) has not, until recently, been examined in detail. However, early work in the VELA-UNIFORM program and some recent work have indicated that discrimination will undoubtedly be more difficult at the shorter distance ranges. Nonetheless, if regional discrimination criteria can be developed and, if high quality land-based stations at regional distances are available, discrimination at significantly lower magnitude thresholds becomes a definite possibility.

The solution of the discrimination problem requires a detailed understanding of the propagation characteristics of seismic waves along the path(s) between the source and the receiver as well as an understanding of the explosion and earthquake sources under investigation.

The phase of the study reported here deals with seismic wave propagation characteristics from presumed nuclear explosions at the USSR East Kazakh test site as observed at WWSSN stations outside the Soviet Union. We then compare these results with earlier observations for PNE's on the Russian Platform. In the future, we will study events from the eastern portion of the USSR, thus completing the geographic coverage of the region.

PROPAGATION OF HIGH FREQUENCY Lg

In many areas of the world Lg(Z) is commonly the largest amplitude phase recorded at regional distances on short period seismographs of the World Wide Standard Station Network (WWSSN) type. Lg(Z) is usually considered to be a superposition of higher mode Rayleigh waves, and it is typically observed to have a group velocity of approximately 3.5 kms/sec., i.e. the group velocity associated with minima of the higher mode dispersion curves. The frequency of Lg(Z) is commonly 1 to 3 hertz, although higher and lower frequencies are present and observed particularly in spectral studies of Lg(Z).

In an earlier study (Pomeroy and Nowak, 1978), it was noted that Lg(Z) amplitudes from nuclear explosions on the Russian Platform (western USSR) and from a few earthquakes in the same area were commonly observed to be of the same size as the P waves from the same event. This result was in sharp contrast to earlier studies in eastern North America (Pomeroy and Nowak, 1977) and in Africa. To investigate this phenomena further, in this study, twenty-five explosions at the E. Kazakh test site and four other explosions (Table I) have been analyzed in addition to five earthquakes in the Gazli series (Table II). In general, all of the E. Kazakh explosions as recorded at the WWSSN stations KBL and MSH exhibit the same characteristics, i.e. Lg(Z) amplitudes of the same order of magnitude in size as the recorded P wave.

Similar techniques to those utilized in earlier investigations were applied to these data. These include:

1. A comparison of Lg(Z) and P(Z) wave amplitudes
2. A determination of the ratio of Lg/P amplitude ratios as a function of distance.
3. A determination of the variations in the group velocity of Lg(Z) particularly between explosions and earthquakes.
4. A study of the distribution of energy in the Lg(Z) wave train.
5. Attenuation of Lg(Z)

Figure 1 shows the location of the events studied here with respect to continental and political boundaries. Only propagation paths in the regional distance range (5° - 20°) were studied in detail. The WWSSN stations used in this study are listed in Table III.

TABLE I

E. Kazakh Explosions* Used in this Study

Event	Date	Origin Time	Latitude (N)	Longitude (E)
1	09/29/68	03:42:58	49.77	78.19
2	11/09/68	02:53:58	49.79	78.04
3	12/18/68	05:01:57	49.72	78.06
4	03/07/69	08:26:58	49.81	78.15
5	07/04/69	02:46:57	49.75	78.19
6	09/11/69	04:01:57	49.70	78.11
7	10/01/69	04:02:58	49.81	78.21
8	7/21/70	03:02:57	49.95	77.75
9	11/04/70	06:02:57	49.97	77.79
10	12/17/70	07:00:57	49.73	78.13
11	04/25/71	03:32:58	49.82	78.07
12	05/25/71	04:02:58	49.80	78.21
13	10/09/71	06:02:57	50.00	77.70
14	02/10/72	05:02:57	49.99	78.89
15	03/28/72	04:21:57	49.73	78.19
16	11/02/72	01:26:58	49.91	78.84
17	02/16/73	05:02:58	49.83	78.23

TABLE I (Continued)

Event	Date	Origin Time	Latitude (N)	Longitude (E)
18	07/10/73	01:26:58	49.78	78.06
19	07/23/73	01:22:58	49.99	78.85
20	05/31/74	03:26:57	49.95	78.84
21	12/27/74	05:46:57	49.96	79.05
22	02/02/75	05:32:58	49.82	78.08
23	06/08/75	03:26:58	49.76	78.09
24	12/13/75	04:56:57	49.80	78.20
25	12/25/75	05:16:57	50.04	78.90
		Other Explosions* Used in this Study		
26	12/06/69	07:02:57	43:83	54.78
27	12/12/70	07:00:57	43.85	54.77
28	12/23/70	07:00:57	43.83	54.85
29	04/11/72	06:00:05	37.37	62.00

* Dahlman and Israelson (1977)

TABLE II

GAZLI EARTHQUAKES

Event	Date	Origin Time	Latitude (N)	Longitude (E)
1	04/08/76	22:54:17.8	40.487	63.650
2	04/12/76	16:12:58.9	40.456	63.610
3	04/17/76	20:21:47.2	40.446	63.686
4	04/18/76	22:37:39.7	40.265	63.812
5	04/21/76	22:33:29.8	40.550	63.846

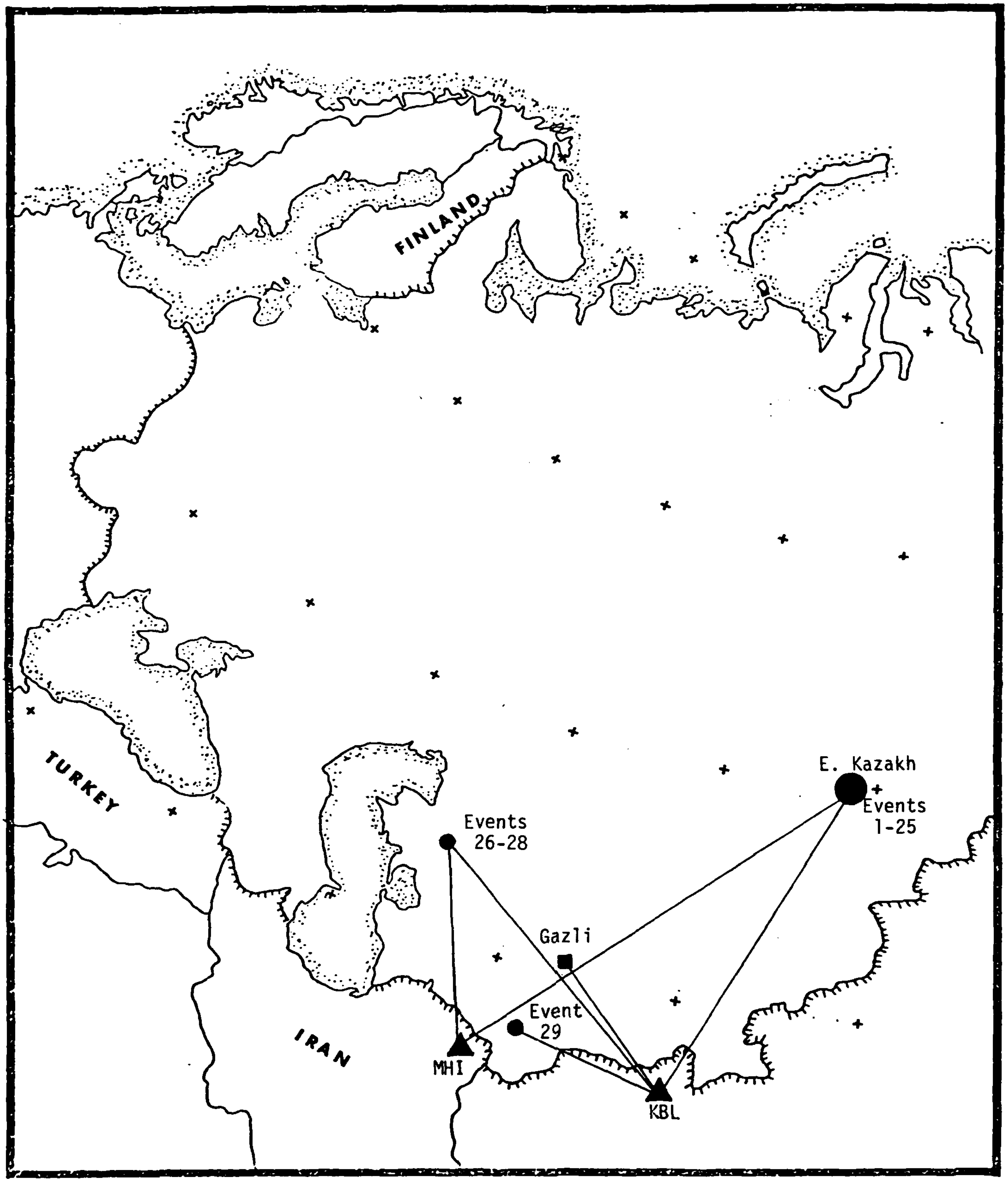

Figure 1. Location Map of Explosions and Earthquakes used in this Study.

TABLE III

WWSSN STATIONS

Station Name	Abbreviation	Latitude	Longitude	Location
Kabul	KBL	34.541 N	69.043 E	Afghanistan
Mashhad	MHI	36.3000 N	59.4945 E	Iran

1. <u>A comparison of Lg(Z) and P(Z) wave amplitudes.</u>

If Lg(Z) amplitudes are significantly larger than P wave amplitudes in the regional distance range, then Lg(Z) will be the only phase observed at or below some magnitude threshold. Earlier observations of events on the Russian Platform indicated that, unlike eastern North America and Africa, Lg(Z) amplitudes were the same order as P wave amplitudes at least for the events studied as recorded at WWSSN stations outside the USSR.

In Figure 2., Lg(Z) wave amplitudes are plotted (in millimicrons) against P(Z) amplitudes (in millimicrons) for all of the explosions listed in Table I. The following points should be noted in Figure 2:

a. All of the explosion data from the eastern Kazakh area generally fall below the line Lg = P in the figure indicating that these events fall in the same range as the explosions on the Russian Platform studied earlier. Three E. Kazakh explosions from the earlier study also fall in the same range. These data are shown as open circles in Figure 2.

b. The explosions in other areas tend to fall above the E. Kazakh data and, in fact, events 27, 28 and 29 have at least one data point above the line Lg = P.

In Figure 3., a composite of explosion data obtained to date from the Russian Platform, E. Kazakh and other test sites is presented. Here the E. Kazakh data fall below much of the data obtained on the Russian Platform again indicating the smaller amplitudes in Lg(Z) relative to P(Z).

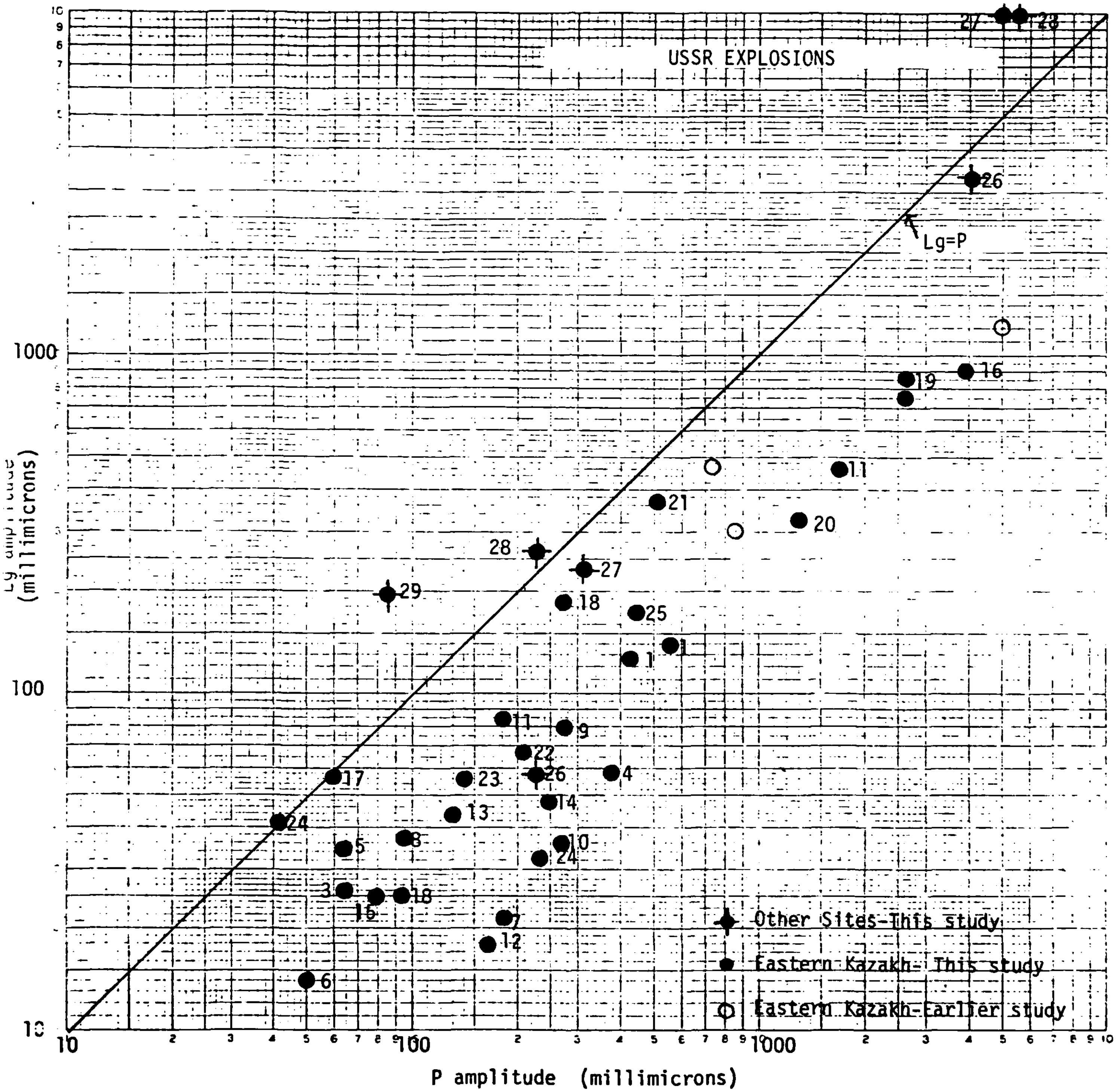

Figure 2. A Comparison of Lg(Z) and P(Z) Amplitudes for the Explosions Studied.

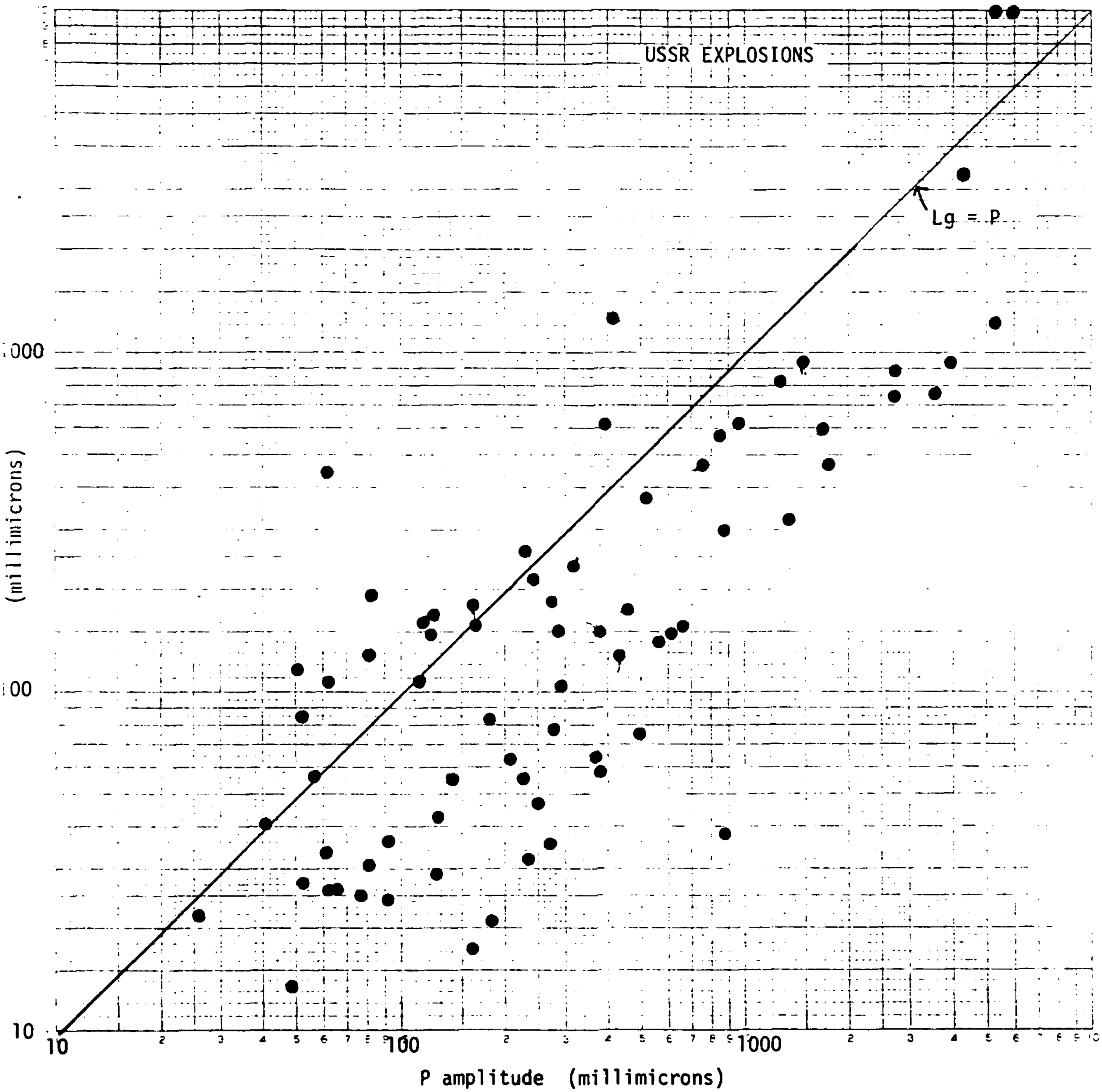

Figure 3. A Composite of Explosion Data from this and Earlier Studies of the USSR Comparing Lg(Z) and P(Z) Amplitudes.

Figure 4 is a comparison of Lg(Z) to P(Z) amplitudes for five Gazli earthquakes as recorded at KBL. Although all these events were recorded at one station, it is interesting to note the relatively small scatter among these (presumably complex) earthquake events and the relatively greater scatter among the explosions (presumably simpler sources) as recorded at KBL and MHI from one area. A further point to be noted here is that all of the Lg(Z) amplitudes are significantly greater than the P(Z) amplitudes.

A composite of this Gazli earthquake data with that of other earthquakes in the western USSR is presented in Figure 5.

The results of this investigation should be contrasted with data from earthquakes reported by Nersesov and Rautian (1968) as summarized by Shishkevish (1979). These authors report that along a profile of seismic stations from Lake Baikal to the Pamirs, earthquakes occuring in the Baikal region, Sinkiang, the Gobi desert, southwest China and the Himalayas generated Lg/P ratios up to 100. Figures 10 - 14 show the Lg/P amplitude ratios obtained by these authors for each region. As shown in Figure 14, crossing the Himalayas significantly reduces the ratio to approximately 1.0 (or 0.0 on our logarithmic plot.) Thus the reader should be cautioned that the high Lg/P ratios recorded at stations in the USSR from events in Baikal or along the USSR border may not be directly comparable with the data presented here and in earlier reports on events within the USSR recorded at stations outside the USSR.

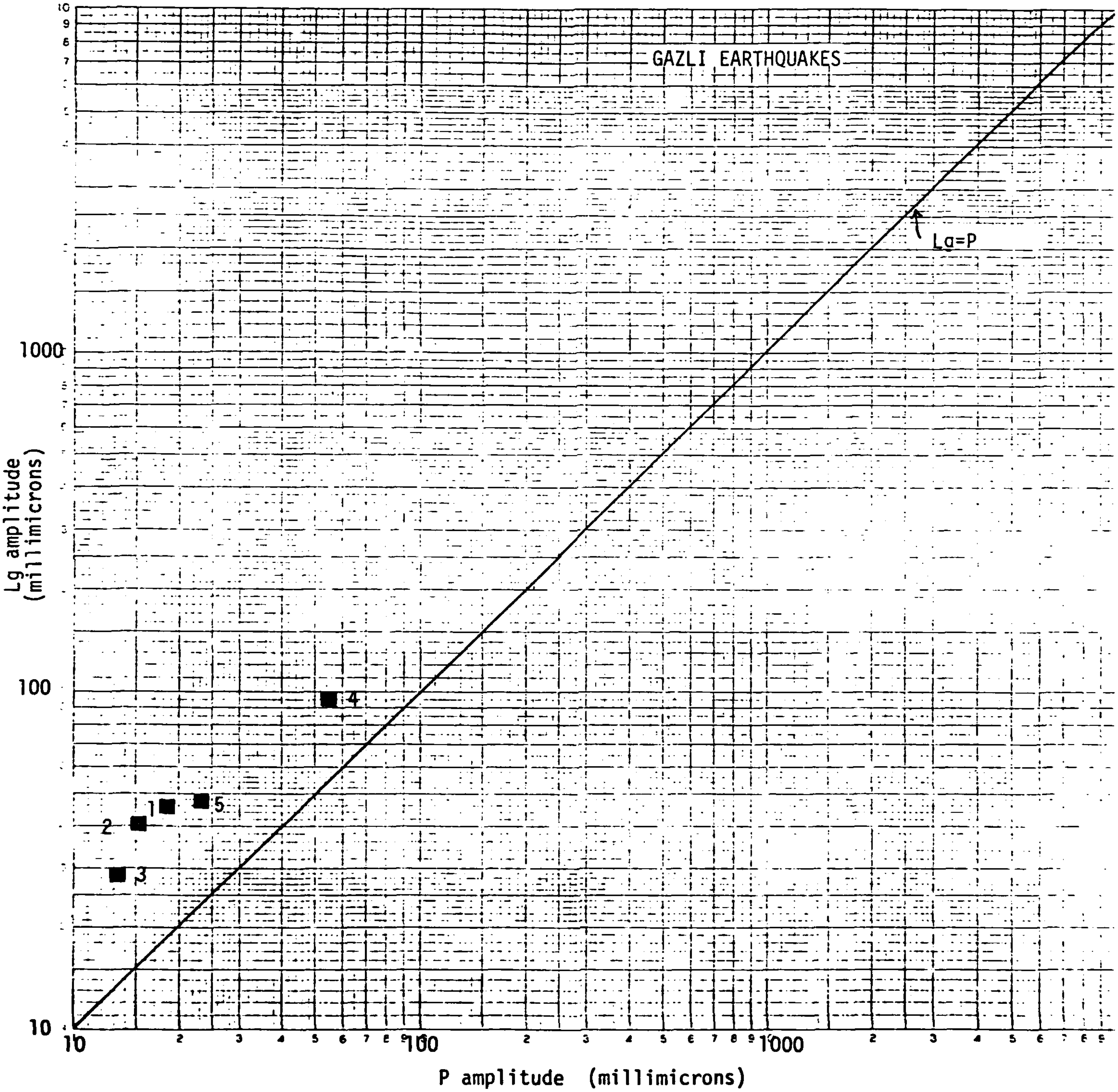

Figure 4. A Comparison of Lg(Z) and P(Z) Amplitudes for the Gazli Earthquakes.

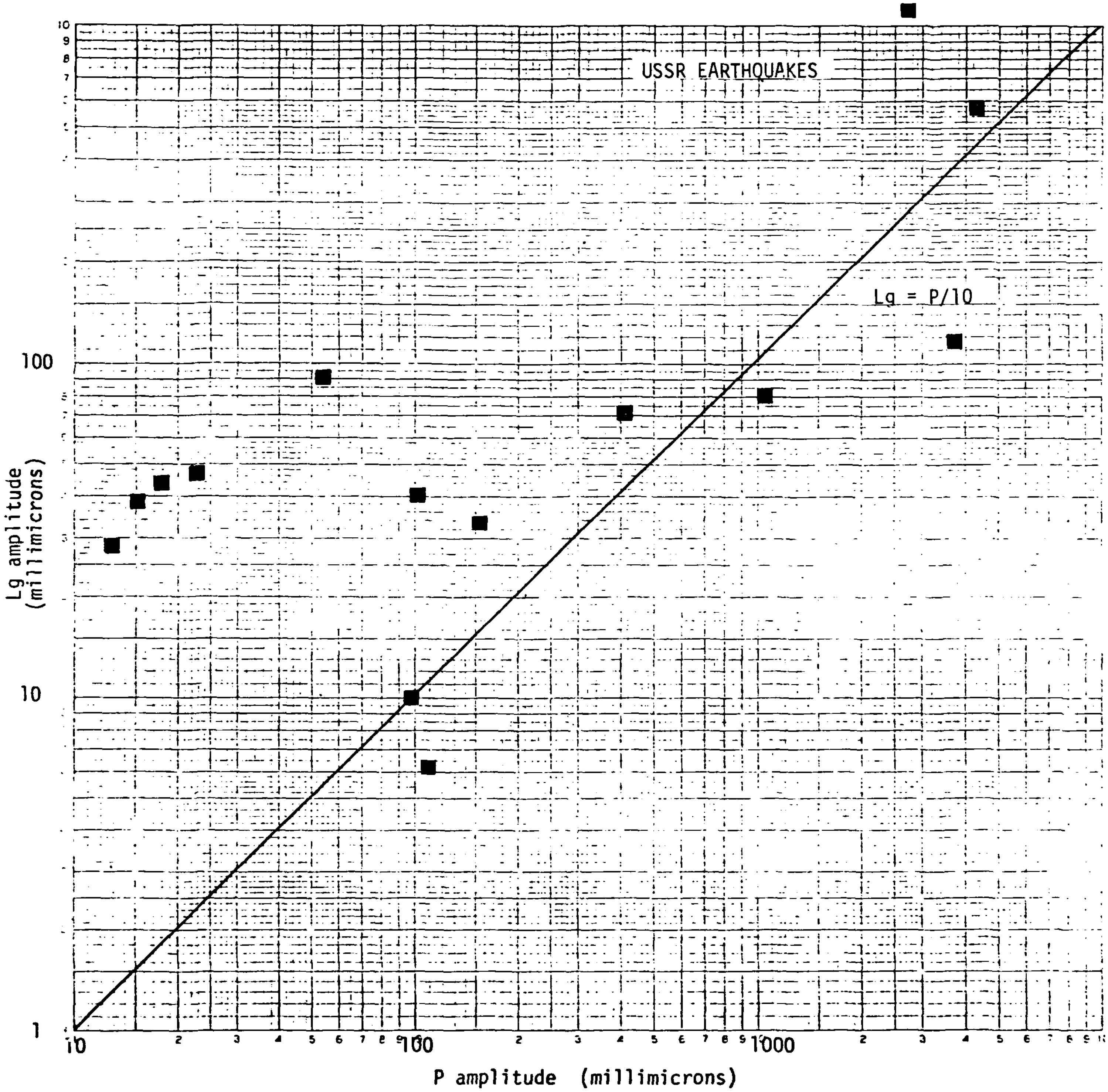

Figure 5. A Composite of the Earthquake Data from this and Earlier Studies Comparing Lg(Z) and P(Z) Amplitudes.

2. Lg/P amplitude ratios.

Seismic records at KBL and MHI for ninety-four presumed explosions at the E. Kazakh site were examined in this study, and twenty-five events were determined to be suitable for further analysis. In Figure 6, the ratio $\mathrm{Log}_{10}\left[\frac{A/T\ Lg}{A/T\ P}\right]$ is plotted for these twenty-five events as a function of distance. Since these events are from approximately the same area, the data tend to cluster at 16.5 - 17° for KBL and 19 - 19.5° for MHI. The most striking feature of this plot is the wide variation in the value of this ratio at a single station. The variation from 0.0 to -1.1 at KBL and -0.7 to +0.2 at MHI is extremely interesting in view of the relative similarity of the sources. Also shown in this figure are the ratios for events 26 through 29 as recorded at KBL and MHI. Some of these data fill out the data set obtained previously from events on the Russian Platform.

Figure 7 shows the ratio obtained for the five Gazli earthquakes analyzed in this study. The relative clustering of the ratios for these events is in sharp contrast to the scatter demonstrated by the explosion data.

Figure 8 shows the range of values for the logarithm of the amplitude ratio plotted along the paths studied here.

Figure 9 is a composite of the ratio data obtained in this study with that for explosions and earthquakes studied earlier.

It is difficult to see clear separation of the explosion and earthquake populations in this data and undoubtedly regional or local analyses will be required to separate events.

Values of the logarithm of the amplitude ratio are tabulated in Table IV for the explosions studied and in Table V for the Gazli earthquakes.

Data from USSR authors on amplitude ratios are presented in Figures 10 to 14. These data were obtained from stations within the USSR from earthquake events occuring in Baikal, Sinkiang, the Gobi desert, Southwest China and the Himalayas.

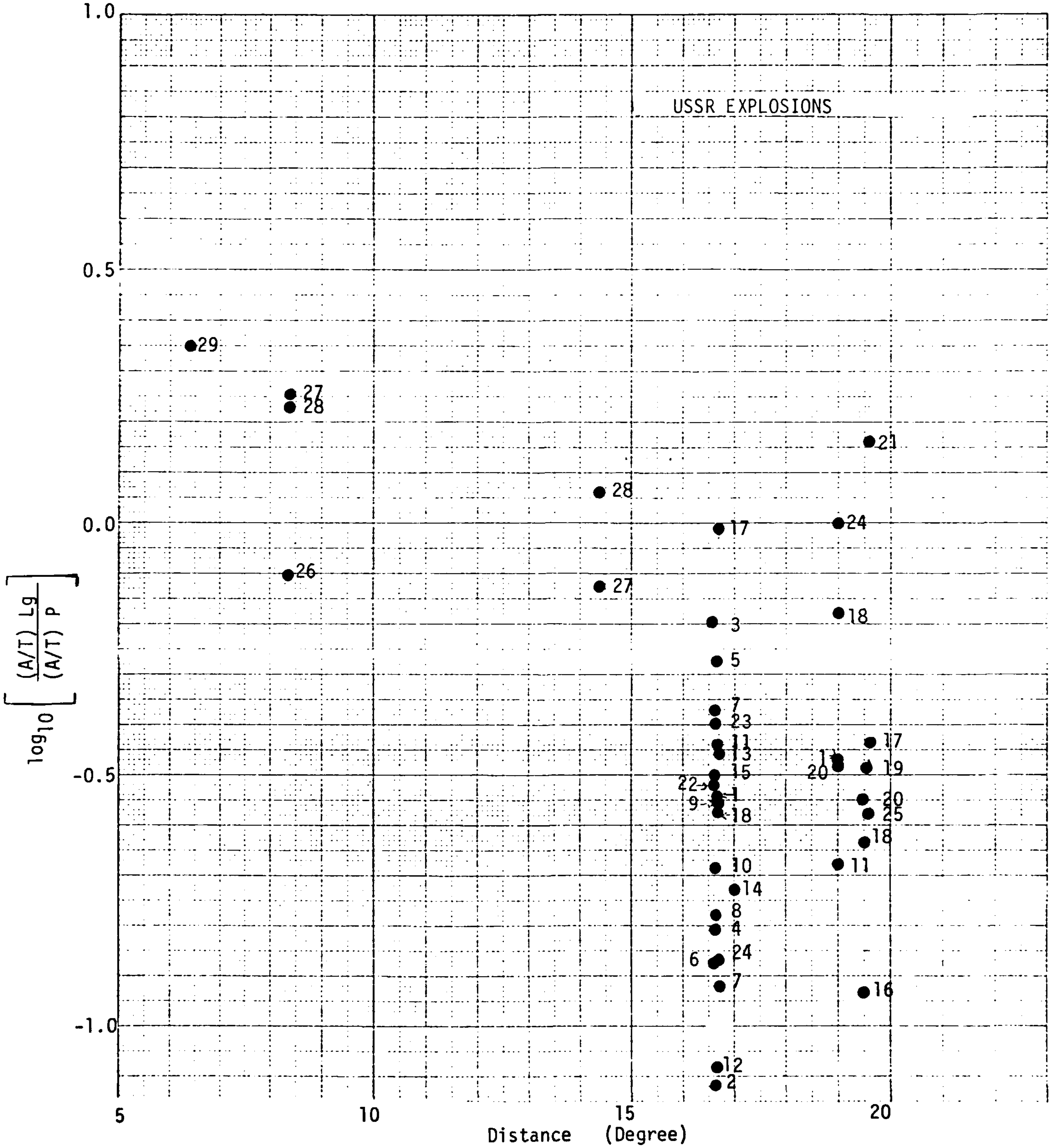

Figure 6. The Logarithm of the Lg(Z) to P(Z) Wave Amplitude Ratio Plotted as a Function of Distance for the Explosions Analyzed in this Study.

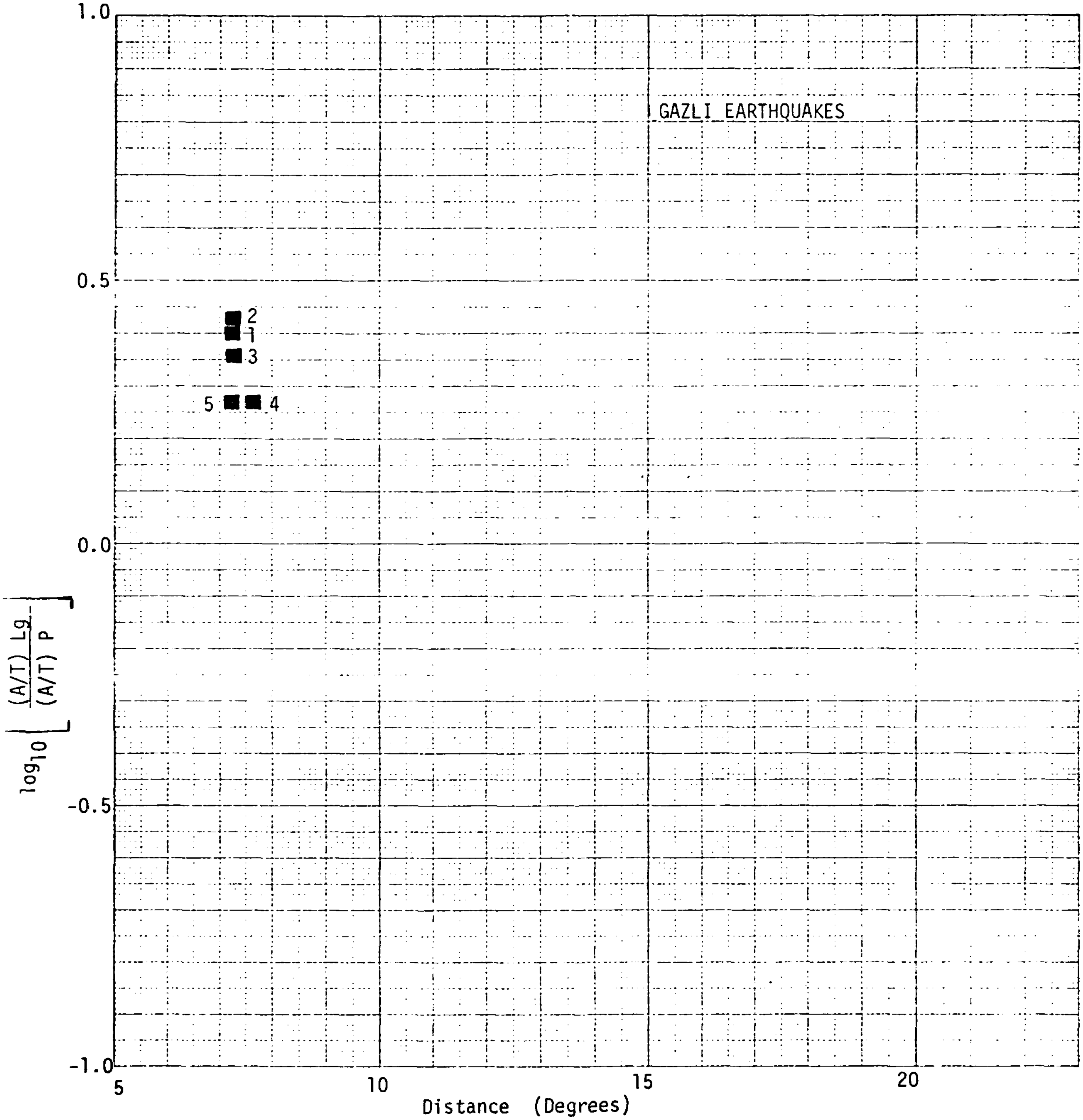

Figure 7. Lg(Z)/P(Z) Amplitude Ratios for Five Gazli Earthquakes as Recorded at KBL.

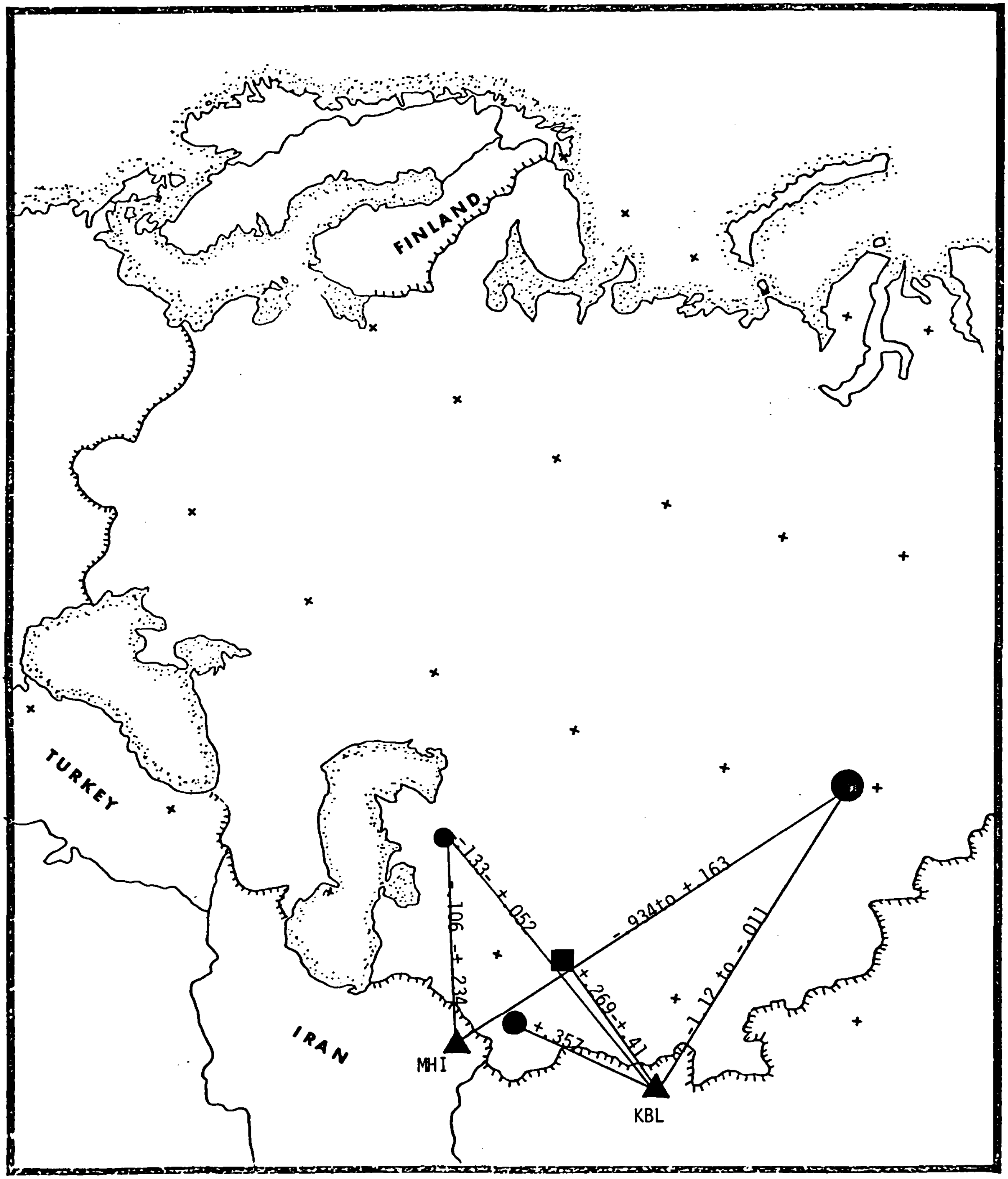

Figure 8. Map Showing Values of Logarithm of Amplitude Ratios for Paths Studied.

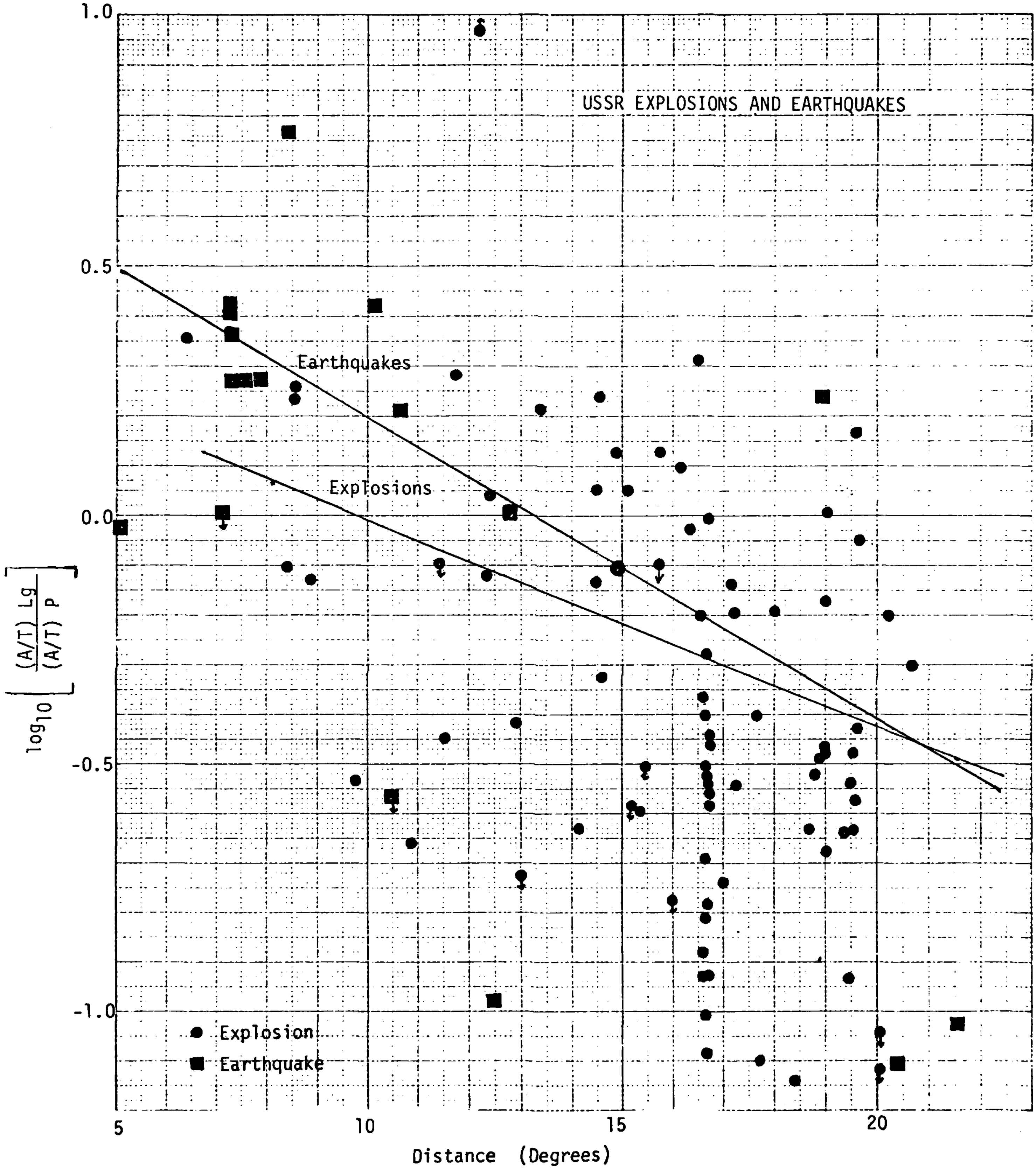

Figure 9. Composite Amplitude Ratios for all USSR Earthquakes and Explosions Analyzed to Date.

TABLE IV

Explosion Data Obtained in this Study

Event	U_{max} of Lg(Z)	$Log_{10}[\frac{A/T\ Lg(Z)}{A/T\ P(Z)}]$	E_H/E_L
1	3.54 KBL 3.5 MHI	-.540 KBL -.477 MHI	
2	3.5 KBL	- 1.12 KBL	
3	3.57 KBL	- .196 KBL	
4	3.60 KBL	- .813	
5	3.66 KBL	- .272	
6	3.5 KBL	- .878	
7	3.6 KBL	- .924	
8	3.53 KBL	- .785	
9	3.27 KBL	- .555	
10	3.59 KBL	- .687	
11	3.53 KBL 3.5 MHI	< - .44 KBL - .677 MHI	
12	3.70 KBL	< - 1.087 KBL	
13	3.58 KBL	- .457 KBL	
14	3.59 KBL	- .735 KBL	
15	3.47 KBL	- .502 KBL	
16	3.20 MHI	- .934 MHI	
17	3.40 KBL	- .011 KBL	
18	3.53 KBL 3.67 MHI	- .576 KBL - .176 MHI	
19	3.20 MHI	- .485 MHI	
20	3.30 MHI	- .55 MHI	

TABLE IV (Continued)

Event	U_{max} of Lg(Z)	$Log_{10}[\frac{A/T\ Lg(Z)}{A/T\ P(Z)}]$	E_H/E_L
21	3.70 MHI	+ .163 MHI	
22	3.60 KBL	- .52 KBL	1.33 KBL
23	3.60 KBL	- .40 KBL	.99 KBL
24	3.54 KBL 3.22 MHI	- .878 KBL 0.0 MHI	.97 KBL .59 MHI
25	3.14 MHI	- .58 MHI	.48 MHI
26	3.46 KBL 3.5 MHI	- .106 MHI	
27	3.5	- .133	
28	3.5 KBL 3.1 MHI	+ .052 KBL + .234 MHI	
29	3.23 KBL	+ .357 KBL	

TABLE V

Gazli Earthquakes Recorded at KBL

Event	$U_{max}Lg(Z)$	$Log_{10}[\frac{A/T\ Lg(Z)}{A/T\ P\ (Z)}]$	Distance Degrees
1	3.07	+ .410	7.3
2	2.99	+ .425	7.3
3	3.12	+ .362	7.27
4	3.07	+ .269	7.07
5	3.03	+ .276	7.28

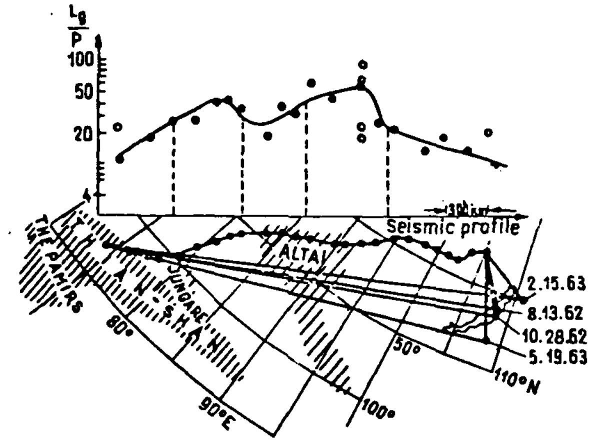

Fig. 10 --Relative amplitude-distance, i.e., A_{Lg}/A_P, curves for seismic waves generated by four earthquakes originating in the Cisbaykal region and recorded by seismographic stations along the Pamir-Lena River profile [25]

- ● - recorded by short-period SKM-3 seismograms
- o - recorded by unspecific long-period (probably SKD) seismograms
- /// - mountain chain

The date identifies the earthquake. A few straight lines show the path from the earthquakes to the seismographic stations

(From Shishkevish, 1979)

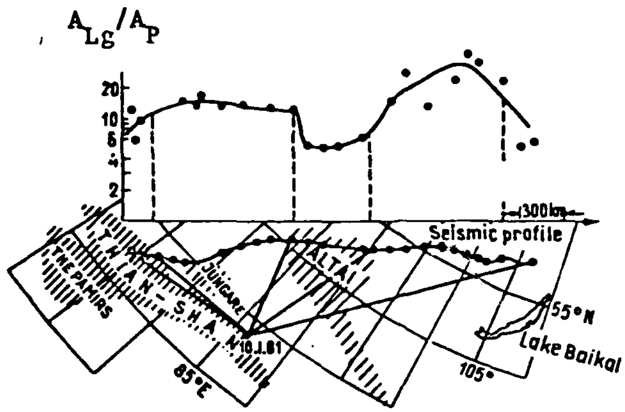

Fig. 11--Relative amplitude-distance, i.e., A_{Lg}/A_P, curves for seismic waves generated by four earthquakes originating in the Sinkiang province and recorded by seismographic stations along the Pamir-Lena River profile [25]

● - recorded by short-period SKM-3 seismograms

o - recorded by unspecified long-period (probably SKD) seismograms

/// - mountain chain

The date identifies the earthquake. A few straight lines show the paths from the earthquakes to the seismographic stations

(From Shishkevish, 1979)

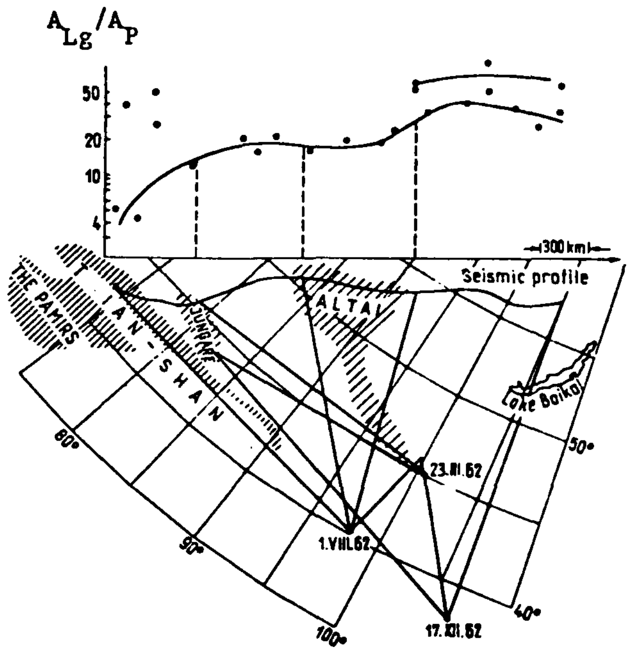

Fig. 12--Relative amplitude-distance, i.e., A_{Lg}/A_P, curves for seismic waves generated by four earthquakes originating in the Gobi desert and recorded by seismographic stations along the Pamir-Lena River profile [25]

- ● - recorded by short-period SKM-3 seismograms
- o - recorded by unspecified long-period (probably SKD) seismographs
- ///- mountain chain

The date identifies the earthquake. A few straight lines show the paths from the earthquakes to the seismographic station

(From Shishkevish, 1979)

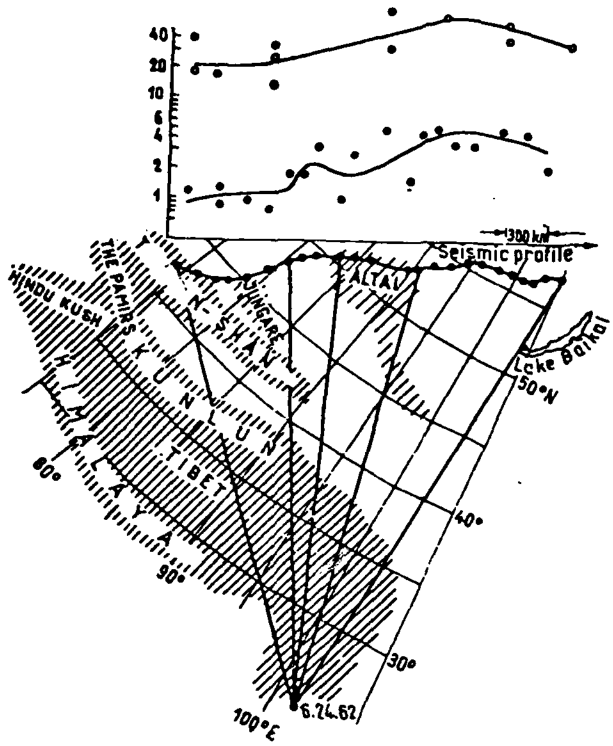

Fig. 13--Relative amplitude-distance, i.e., A_{Lg}/A_P, curves for seismic waves generated by four earthquakes originating in South West China and recorded by seismographic stations along the Pamir-Lena River profile [25]

- • - recorded by short-period SKM-3 seismograms
- o - recorded by unspecified long-period (probably SKD) seismograms
- /// - mountain chain

The date identifies the earthquake. A few straight lines show the paths from the earthquakes to the seismographic stations

(From Shishkevish, 1979)

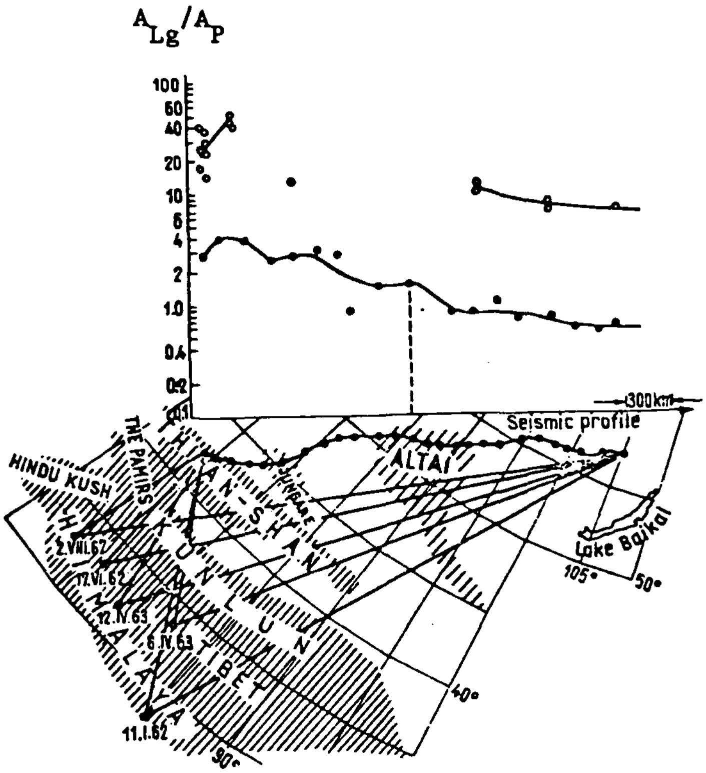

Fig. 14--Relative amplitude-distance, i.e., A_{Lg}/A_P, curves for seismic waves generated by four earthquakes originating in the Himalayas and recorded by seismographic stations along the Pamir-Lena River profile [25]

- ● - recorded by short-period SKM-3 seismographs
- o - recorded by unspecific long-period (probably SKD) seismographs
- /// - mountain chain

The date identifies the earthquake. A few straight lines show the paths from the earthquakes to the seismographic station

(From Shishkevish, 1979)

3. Group velocity of Lg(Z).

Previously, it has been reported that group velocity observations of Lg(Z) in the Russian Platform area essentially encompass the normally observed value of 3.5 km/second. The explosions studied earlier fell slightly below that value while the few earthquake points averaged to approximately that value. To test the variability of this parameter for a variety of explosive sources, the group velocity for the maximum amplitude in Lg(Z) was determined for the twenty-five E. Kazakh explosions listed in Table I as recorded at KBL and MHI. These data are presented in Figure 15. A variation of 3.27 to 3.70 km/second is observed at KBL with most of the measurement between 3.45 and 3.60 km/second. At MHI, the data are sparce but scatter between 3.14 and 3.70 km/second. Possible causes of this variation include:

1. Location errors leading to errors in calculating group velocity.
2. Crustal structure variations related to differences in propagation paths due to small differences in source location. This factor could account for most, if not all, the observed variation.
3. Effects of varying source depth giving rise to differences in the excitation of higher mode surface waves and thus shifting the location of the maximum amplitude in the Lg(Z) wave train.

The data presented here require further analysis to separate the latter two effects.

Data for the other USSR explosions analyzed (Events 26 - 29) in Table I) are presented in Figure 16. The low group velocities for events 27 - 29 as recorded at KBL at 6.35° and MHI at 8.4° are probably the result of the crustal structure, but further investigations are needed to clarify this point.

Group velocity data for five Gazli earthquakes are presented in Figure 17. The cause of the low group velocities is currently under investigation.

A map showing the range of group velocity values for the maximum amplitude of Lg(Z) plotted on the respective propagation paths is presented in Figure 18.

In Figure 19, a composite graph of all group velocity data as a function of distance is shown.

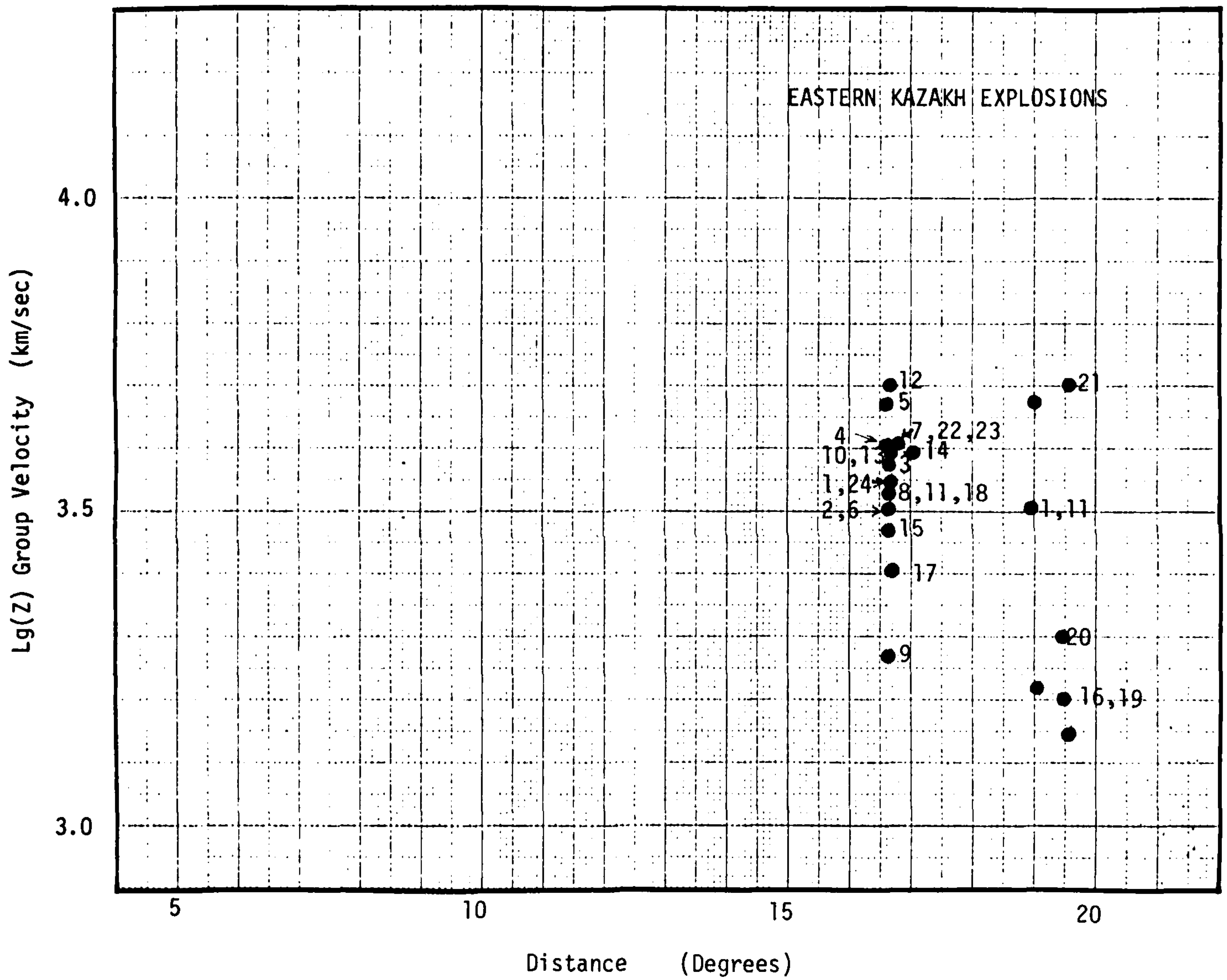

Figure 15. Group Velocity Data for Twenty-five E. Kazakh Events

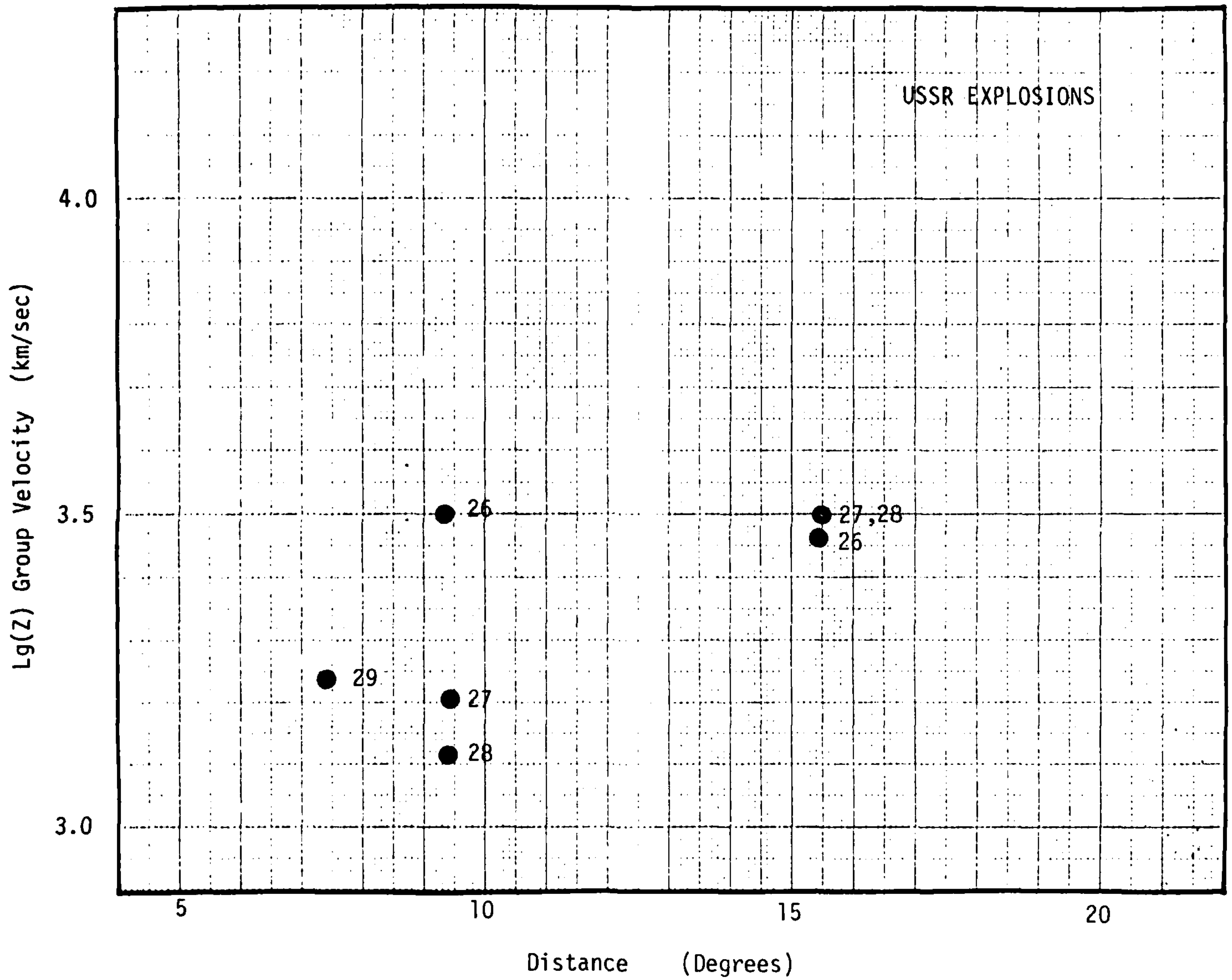

Figure 16. Group Velocity Data for Four USSR Presumed Explosions in Other Areas.

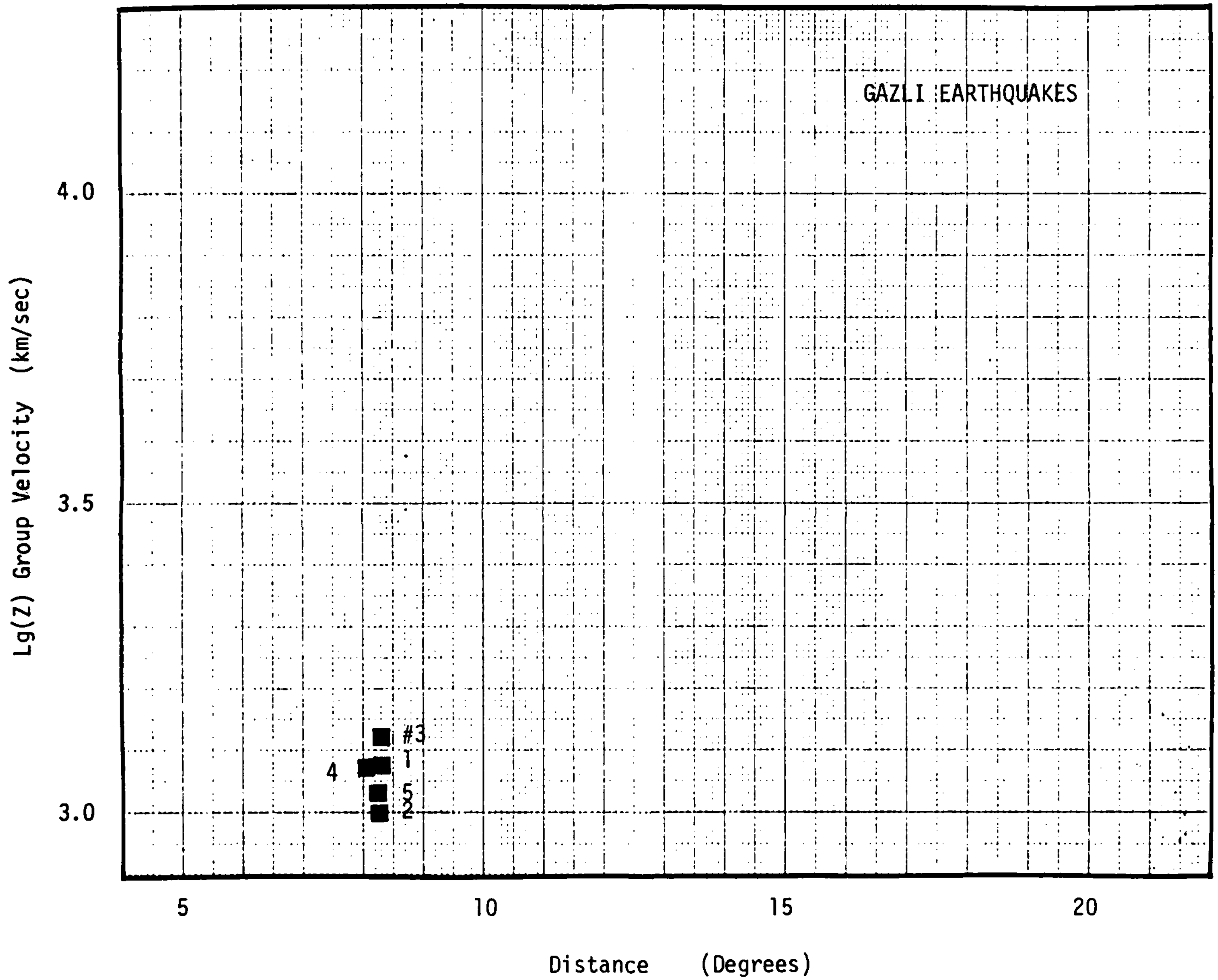

Figure 17. Group Velocity Data for Five Gazli Earthquakes.

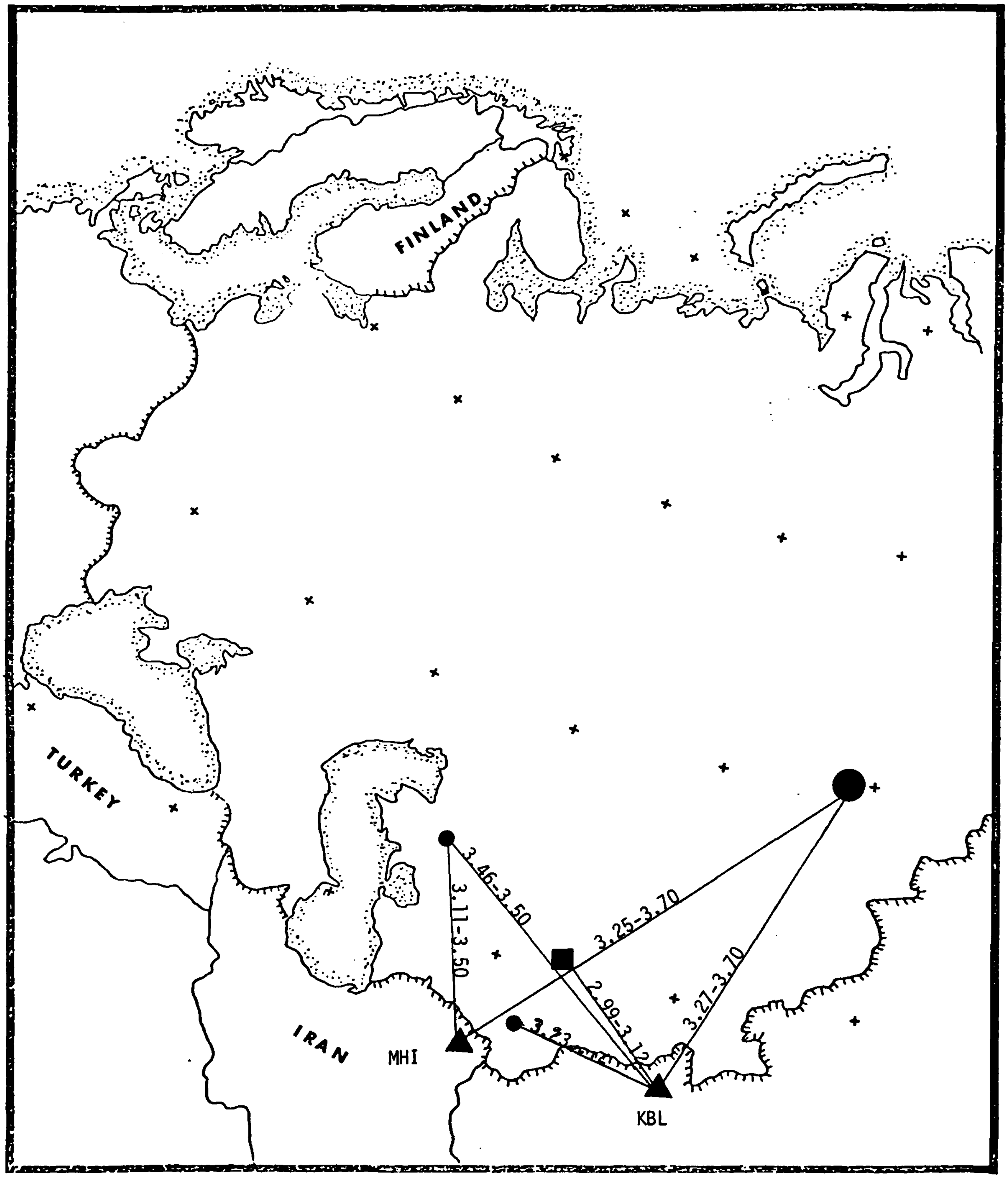

Figure 18. Map Showing Group Velocity Variations for Events Studied.

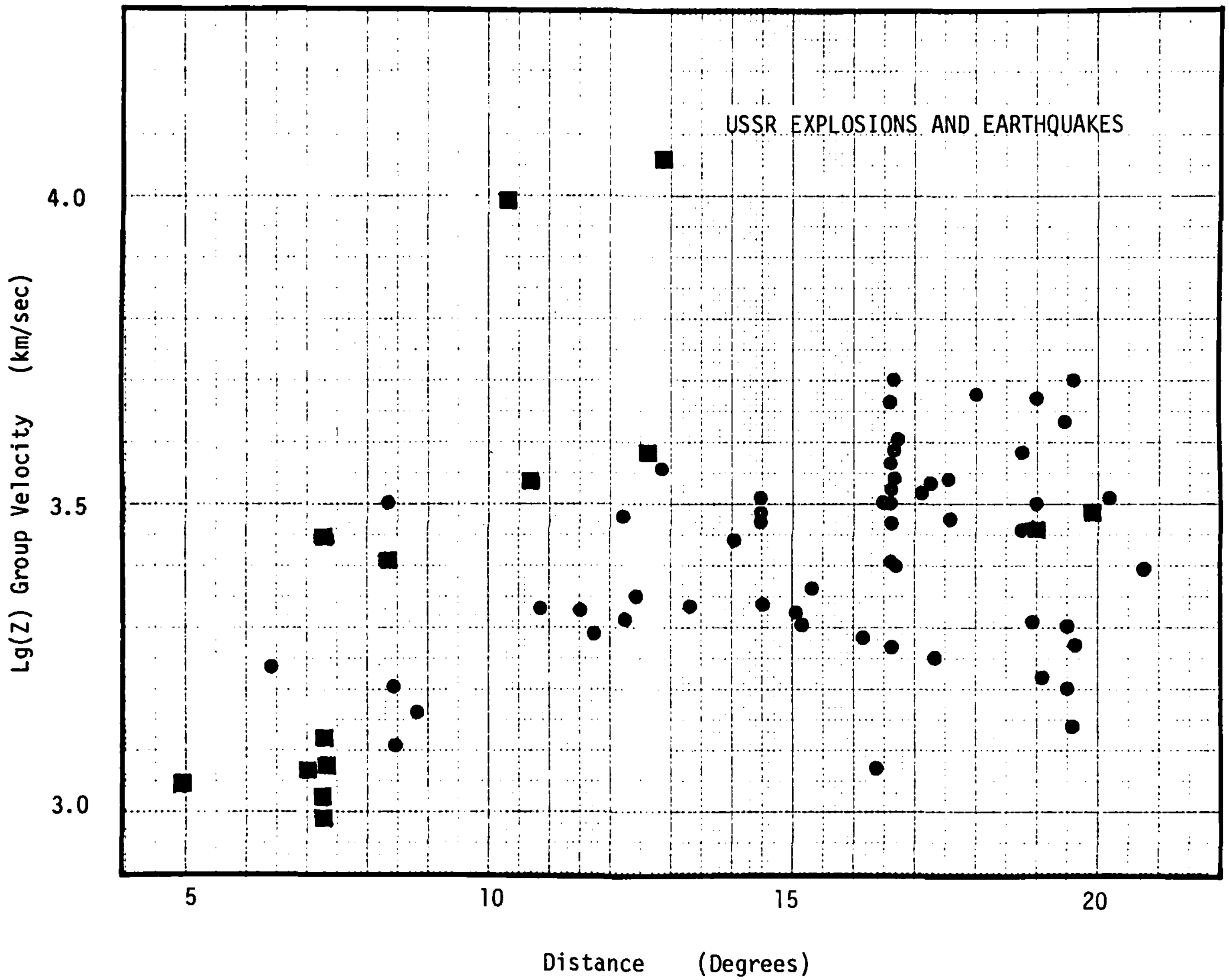

Figure 19. Composite of all Group Velocity Values for the Maximum Amplitude of Lg Studied to Date.

4. Energy ratios of Lg(Z).

In Semi-Annual Technical Report No. 2 under this contract, energy ratios in Lg(Z) were determined for a large number of explosions in the Russian Platform area. The energy ratio method used involved the selection of two group velocity windows of the same length — 4.0 - 3.4 km/sec. and 3.4 - 2.8 km/sec. The faster window encompasses the range of group velocities which might be encountered in the higher Rayleigh modes while the slower window includes group velocity values normally associated with the fundamental Rayleigh mode in this frequency range. To quantify the amount of energy in each group velocity window, the area enclosed by the envelope of the waves was measured by a method analogous to the AR method used on long period surface waves. The areas measured are proportional to the energy carried in the window. E_H is used to designate the high velocity energy and E_L to designate the low velocity energy.

It was possible to apply this technique to the visible recordings of five additional E. Kazakh events and the results are shown in Figure 20. The logarithm of the energy varies from .85 to 1.33 at the KBL station and from .48 to .83 at the MHI station. Again, the real variation in the energy ratio may be related to differences in crustal properties along the different propagation paths involved or it may be related partly to variations in the depth of the source. If Lg(Z) is the result of a superposition of higher mode Rayleigh waves, then differences in the depth of the source should result in differences in the relative excitation of the various higher modes which would in turn result in variations in this ratio.

The results of the analyses here are plotted together with the earlier results from the Russian Platform in Figure 21. The E. Kazakh data are consistent with the earlier data but are in sharp contrast to energy ratio data obtained in eastern North America.

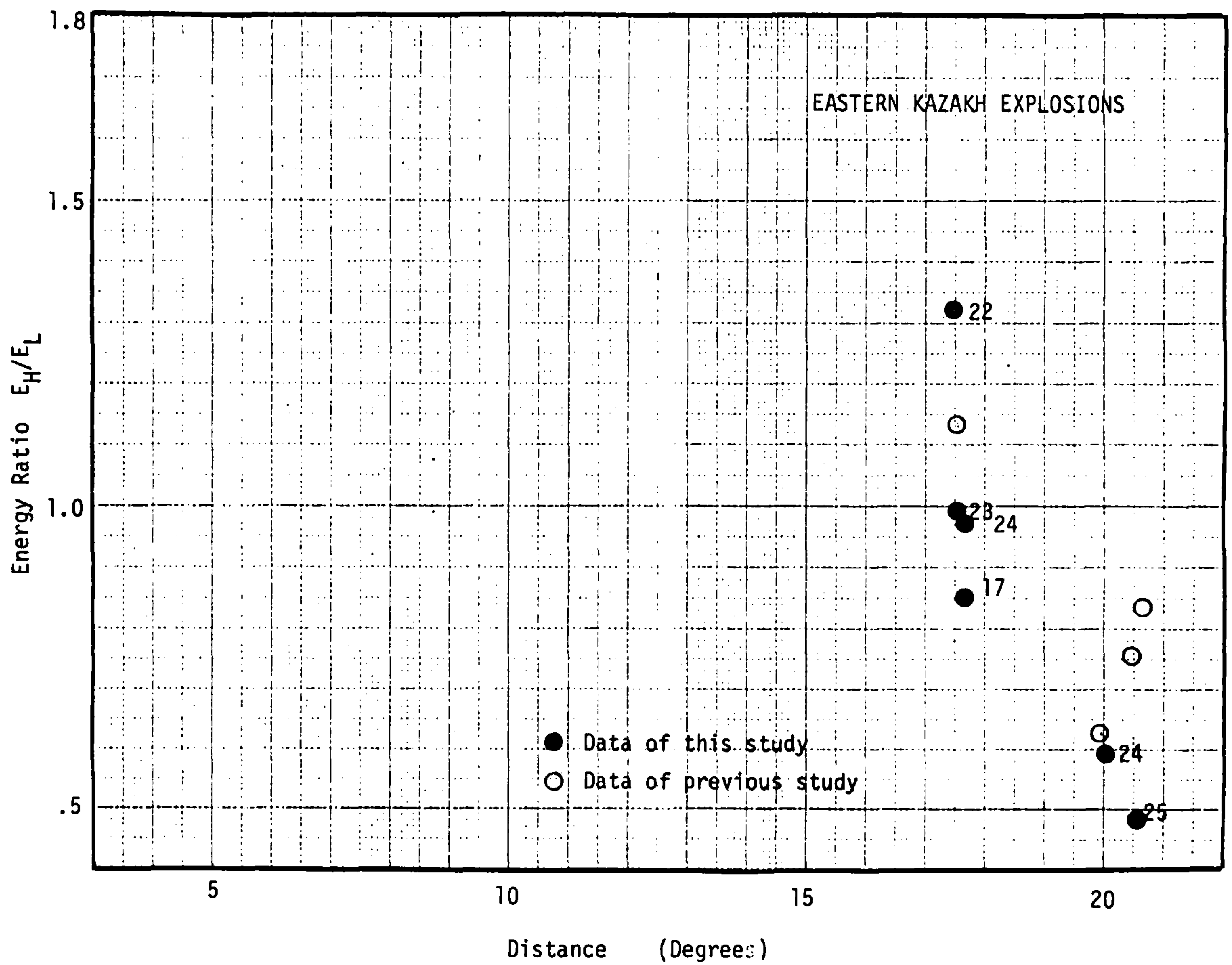

Figure 20. Energy Ratio for E. Kazakh Events.

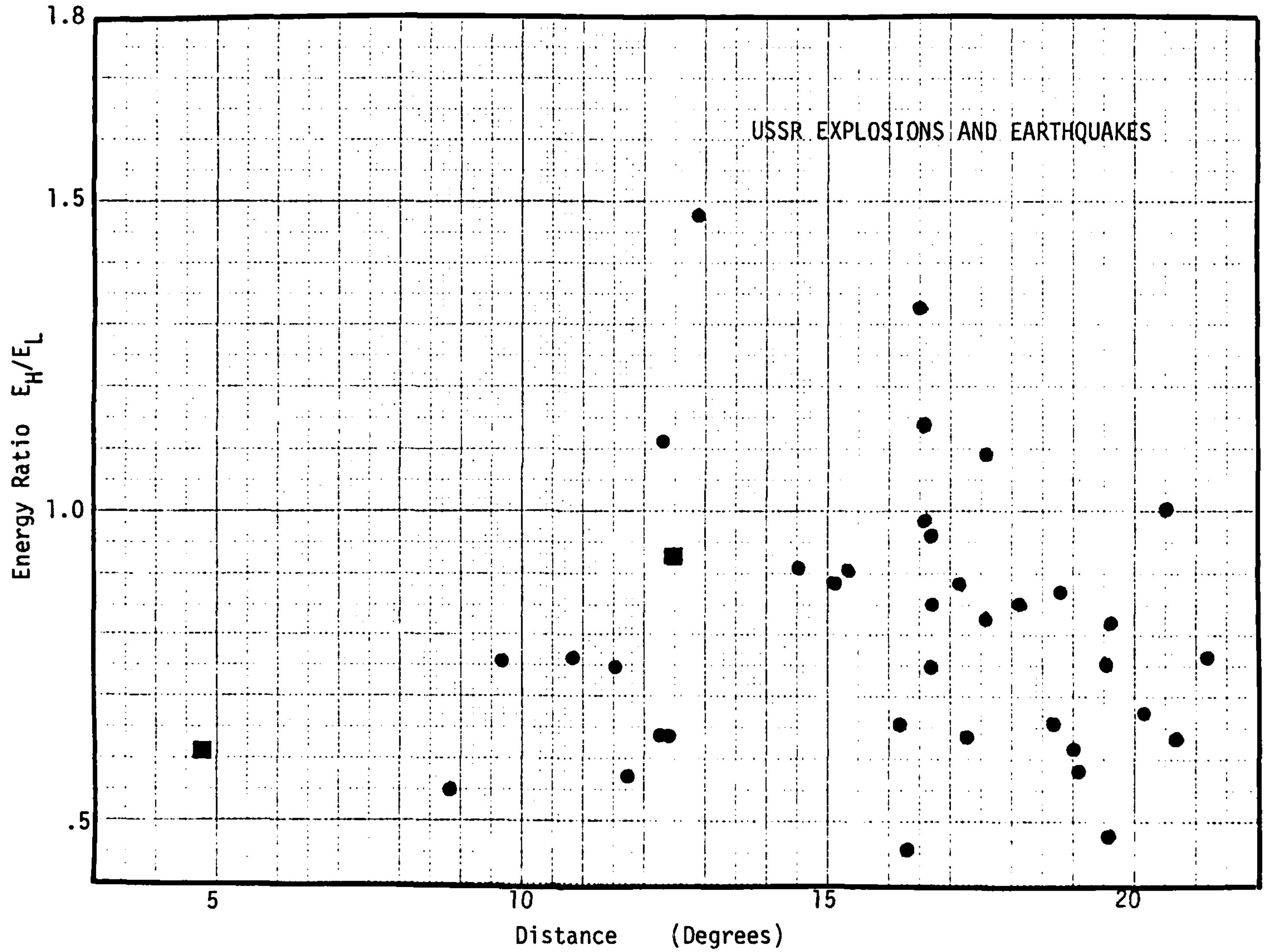

Figure 21. Energy Ratio Data for Explosions and Earthquakes in the USSR.

5. Lg(Z) Attenuation

Lg(Z) wave amplitudes for the twenty-five Eastern Kazakh events and the other four events (all listed in Table I) were normalized to magnitude $m_b = 4.4$ and plotted against epicentral distance in Figure 19. The normalization was carried out in the following manner:

1. The yields of the 25 events were taken from estimates published by Dahlman and Israelson (1977).
2. These yields were converted to body wave magnitudes using the relationship $m_b = .93^{10} \log Y + 3.49$ developed by Ericsson from Nevada Test Site data. Ericsson indicated that the relationship was also applicable to events in the USSR but its validity remains to be demonstrated.
3. The magnitudes were then normalized to $m_b = 4.4$ using the relationship $A_{(normalized)} = A \times 10^{(4.4 - m_b)}$.

As we have stated earlier, this method leaves much to be desired but it is, at least, an attempt to determine a characteristic Q for the region. The data are presented in Figure 22 together with earlier attenuation data from the Russian Platform which was normalized in the same manner.

Over limited distance ranges, the attenuation curve can be approximated by a straight line. In Figure 22, a straight line approximation to Eastern North American attenuation data published by Pomeroy (1977) is shown. On this curve, the amplitude is proportional to approximately $\frac{1}{\Delta^3}$. This curve can be seen to encompass the Lg amplitude data but the data tend to show an even steeper slope giving some validity to a value lying below $\frac{1}{\Delta^3}$. Antonova et al.(1978) using earthquake data recorded in Tien Shan determined a slope for the attenuation of -1.61, i.e. amplitude is proportional to $\frac{1}{\Delta^{1.6}}$. This value is lower than our data set, i.e. lower attenuation of Lg(Z) with distance. Currently, we are attempting to determine values of the coefficient of analastic attenuation γ on a regional basis to determine Q for different paths.

Antonova et al. (1978) also published composite amplitude vs distance curves for Lg from five earthquakes originating in Central Asia and recorded by seismograph stations located along a profile from North of Lake Baikal to the Pamirs. Four average amplitude points at 500, 1000, 1500 and 2000 kms have been taken from the composite diagram and plotted in Figure 22. Those points have been normalized to the data of this study by moving the points as a unit vertically until they passed through our data. An examination of Figure 22 indicates the degree of consistency of these points with our explosion data. From their composite curve, the USSR authors indicate that the amplitudes of Lg decrease with distance up to 700 km at a rate proportional to $\frac{1}{\Delta^{1.4}}$ and that the decrease in amplitudes becomes larger at larger distances such that at 2000 kms, the amplitudes of Lg decrease as $\frac{1}{\Delta^{2.2-2.5}}$.

This value at 2000 kms, lying between $\frac{1}{\Delta^{2}}$ and $\frac{1}{\Delta^{3}}$, is not inconsistent with the data derived in this study. As can be seen from Figure 22, the curve published by Pomeroy (1977) for Eastern North America provides a very reasonable approximation to the slope of the USSR earthquake data. Again the USSR earthquake data is derived from earthquake events outside the USSR while our data is from presumed explosions within the USSR recorded outside the USSR. Since the propagation paths for most of the USSR data and all of our data cross major tectonic boundaries, the high attenuation rates are not entirely unexpected.

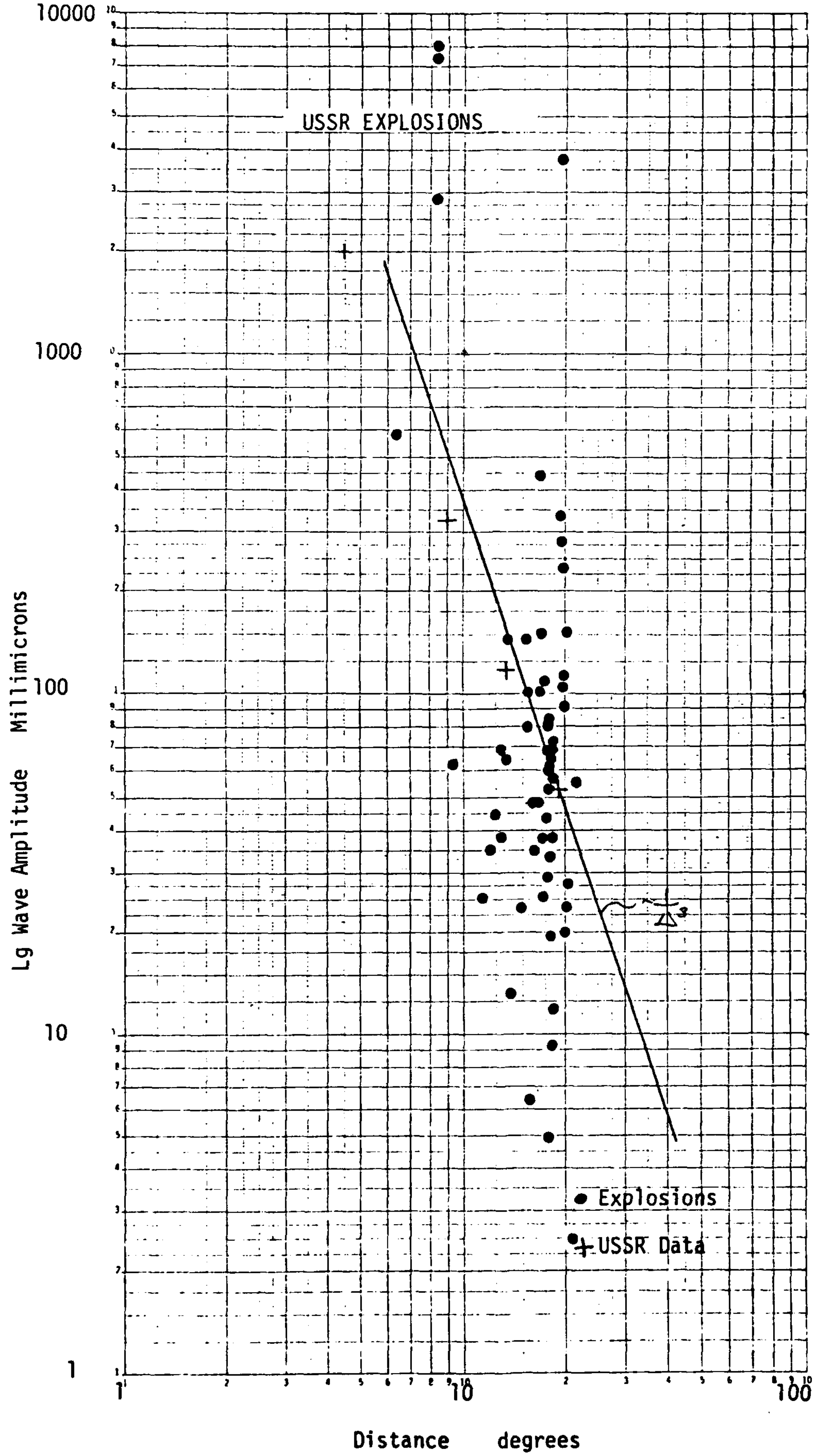

Figure 22. Lg Attenuation for USSR Explosions.

BIBLIOGRAPHY

Antonova, L.V., et al., Experimental Seismic Investigations of the Earth's Interior, Academy of Sciences, Institute of Physics of the Earth, Published by "Nauka", Moscow, 1978.

Dahlman, O. and Israelson, H., 1977 Monitoring Underground Nuclear Explosions, Elsevier Scientific Publishing Co.

Pomeroy, P.W., 1977, Aspects of Seismic Wave Propagation in Eastern North America, A Preliminary Report, Rondout Associates, Stone Ridge, N.Y.

Pomeroy, P.W. and Nowak, T.A., 1978, An Investigation of Seismic Wave Propagation in Eastern North America, Semiannual Technical Report No. 1, Rondout Associates, Inc., Stone Ridge, N.Y.

Pomeroy, P.W. and Nowak, T.A., 1979, An Investigation of Seismic Wave Propagation in Western USSR, Semiannual Technical Report No. 2, Rondout Associates, Inc., Stone Ridge, N.Y.

Shishkevish, C., 1979, Propagation of Lg Seismic Waves in the Soviet Union, Rand, Santa Monica, California.